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ORIGINAL RESEARCH

Marine oil dietary supplementation reduces delayed onset muscle soreness after a 30 km run

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Objective: Runners are prone to delayed onset muscle soreness (DOMS) during long distance training. This especially holds for unaccustomed training volumes at moderate to high intensities. We investigated the effects of a marine oil complex, PCSO-524®, derived from the New Zealand green-lipped mussel (formulated as Lyprinol® and Omega XL®) on DOMS after a 30 km training run.

Methods: Initially, peak oxygen uptake of 32 distance runners (4 female, 28 male; median age 45 years, range 28–53) was measured on a treadmill with a 1.5 km hour^{-1} increase every 4 minutes starting from 8.5 km hour^{-1}. At least 1-week after this initial test, they participated in a 30 km road run at a speed corresponding to about 70% of their individual peak oxygen uptake on a flat terrain. Before and after (0, 24, and 48 hours) the run, blood concentration of creatine kinase (CK) were measured and pain sensation was determined (pain scale from 0 = no pain to 10 = extremely painful). Runners were then matched in pairs based on maximal CK and peak oxygen uptake, and allocated randomly into two different groups. One group was supplemented with 400 mg per day of PCSO-524® for 11 weeks, the other group with an olive oil placebo. After that period, CK and pain sensations were remeasured following a second 30 km run at the same speed and on the same terrain.

Results: The general pattern of soreness in the PCSO-524® supplemented group was reduced by 1.1 units (standard error 0.41) compared to the placebo ($P < 0.05$), the effects being greater in lesser trained runners ($P < 0.05$). CK levels were positively associated with pain sensation ($P < 0.05$), but trends toward lower CK in the PCSO-524® group, which were also more pronounced in the lesser trained runners, were not statistically significant.

Conclusion: Pain sensations experienced by distance runners following a 30 km run were reduced by supplementation with the marine oil complex PCSO-524®, an effect which was greater in lesser trained runners.

Keywords: running, marine oil, DOMS, creatine kinase

Introduction

Post exercise muscle soreness, commonly most intense one to three days after exercise and referred to as delayed onset muscle soreness (DOMS) is thought to be associated with microtrauma to muscle cells and connective tissue[1] and can negatively impact performance.[2] Compared to other endurance sports like swimming, rowing, or cycling, runners are especially susceptible to muscle soreness following training as well as competition, primarily due to the eccentric nature of the leg muscle contraction[3] during the initial phase of foot-ground contact.

Methods adopted to diminish DOMS have been met with limited success,[4] but given that non-steroidal anti-inflammatory medication is considered the most

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reliable,[1] inflammation is likely to play a major causative role. Treatment with non-steroidal anti-inflammatory drugs is not without risk,[5] and anti-inflammatory agents with proven safety profiles are clearly a better option for long term use by athletes. Fish oils may fit into this category as they have been shown to be safe for human consumption and offer benefits to human health,[6] and they have also been shown to modulate the inflammatory response.[7] A marine product from *Perna canaliculus* (green-lipped New Zealand mussel) has attracted attention because of its anti-inflammatory activity[8] and an unusually wide variety of constituent triglycerides, sterol esters, sterols, polar lipids, and free fatty acids.[9] This marine oil is commercially available in combination with olive oil as PCSO-524® or Omega XL® (Great HealthWorks; Hollywood, FL, USA) and anti-inflammatory activity has been demonstrated specifically in this product.[10]

Whether PCSO-524® has any impact on DOMS experienced by distance runners is unknown. As it was important to provide a specific exercise stress to maximize the study's practical significance, rather than a non-specific or unfamiliar exercise in a laboratory,[11] the stimulus chosen was a long distance field run.

Methods

This study protocol was approved by the Ethics committee of the German Sports University, Cologne, Germany.

Overview of study design

Thirty two Caucasian, nonprofessional distance runners (28 male, 4 female) participated in this study. They were recruited from a local running club (Telecom, Bonn, Germany). Prior to the long distance runs, peak oxygen uptake (VO_{2peak}) was measured during an incremental treadmill exercise until subjective exhaustion. At least 1-week after this test, runners participated in a 30 km run at a speed corresponding to about 70% VO_{2peak} on a flat course on asphalt after which pain sensation was assessed within the next three days and serial blood samples were collected for subsequent measurement of creatine kinase (CK) concentration. Runners were then paired as closely as possible for sex, maximal CK concentration, and VO_{2peak} and one runner in each pair was randomly allocated to either the active or placebo group. The active group was provided with capsules containing 50 mg PCSO-524® (Great HealthWorks) and 100 mg pharmaceutical grade olive oil, and the control group with 150 mg placebo capsules containing pharmaceutical grade olive oil, which were identical in appearance to the active capsule. The fatty acid analyses of these capsules are shown in Table 1. The runners were asked to take eight capsules (400 mg active substance) every day during the treatment period of 11 weeks. Following the treatment, the 30 km run was repeated on the same course and at the same speed as the first run, followed by the same regime of recording pain perception and blood collection. A single blind design was employed, runners themselves being unaware of who was supplementing the PCSO-524® (Great HealthWorks) or olive oil control capsules.

Table 1 Percentage of fatty acid content of New Zealand green-lipped mussel capsules (containing PCSO-524®), and the olive oil placebo capsules

FA nomenclature	Fatty acid name	Placebo capsule (olive oil) (%)	PCSO-524® capsules (%)
14:0	Myristic		2.0
16:0	Palmitic	11.1	13.0
16:1	Palmitoleic		2.5
18:0	Stearic	3.2	3.0
18:1	Oleic	78.5	60
18:2ω6	Linoleic	6.5	6
18:3ω3	Alpha-linolenic	0.5	1.0
18:4ω3	OTA		0.1
20:0	Arachidic	0.2	0
20:1	Eicosamonoenoic		0.2
20:4ω6	Arachidonic		0.1
20:4ω3	ETA		0.5
20:5ω3	EPA		5
22:5ω3	DPA		0.2
22:6ω3	DHA		4
Others			2.5

Notes: FA-nomenclature: number of carbon atoms, number of double bonds, and position of the first double bond from the noncarboxylate end.

Laboratory procedures

The treadmill protocol involved a stepwise increase in speed every 4 minutes, starting at 8.5 km · hour^{-1}, with increments of 1.5 km · hour^{-1} and 30 seconds between increments until subjective exhaustion. During the rest periods, blood was taken from an earlobe for determination of lactic acid concentration (Accutrend© Lactate analyser; Roche Diagnostics, Mannheim, Germany). Expired respiratory gas was analyzed using a ZAN 680 spirometry system (JK Medical Systems Private Ltd; Chennai, India) and data, including heart rate, were recorded for further computation during the last 30 seconds of each stage.

In order to measure CK blood plasma concentrations, a 20 microliter whole blood sample was taken from an earlobe with the runner in a seated position, prior to the 30 km run, and again immediately after, 24 hours, and 48 hours post run. Blood samples were analyzed using the Diaglobal test

kit and Vario Photometer DP 300 (Diaglobal GmbH; Berlin, Germany), calculated according to the manufacturer's designated procedures.

Pain was measured using a scale of 0–10; runners were asked to indicate which level best represented pain intensity with 0 representing no pain and 10 indicating extremely severe pain. The runners indicated the level of their pain verbally to one technician during a standardized slow walking procedure in the laboratory.

Statistical procedures

Various models belonging to the class of general linear mixed models were explored, which allowed us to compare the pretreatment to posttreatment changes in CK and DOMS in each group with adjustment for the effects of pretreatment values of these variables as well as the CK before each run. In exploring these models, we considered statistical adjustments for running speed and the number and length of training sessions. We then excluded nonsignificant variables to employ a simplified model to measure the interaction between the treatment and the time of measurement of DOMS and CK (transformed by logarithm to satisfy linearity requirements). In taking the matched pairs into account, this effectively allowed a comparison of the patterns of pretreatment to posttreatment changes in DOMS and CK following the 30 km run in the PCSO-524® (Great HealthWorks) and placebo groups.

Our simplified model had the form:

$$\begin{aligned}&\text{DOMS or Ln CK (30 km run 2–30 km run 1)}\\&\quad=\text{Treatment}+\text{Time}+\text{Treatment}\cdot\text{Time}+\text{Weight}\\&\qquad+\text{Run average speed}+\text{Random pair}+\text{Random}\\&\qquad\text{subject}+\text{Residual error}\end{aligned}\qquad(1)$$

where the response (dependent) variable is the difference in DOMS (or LnCK) between the pre and postsupplementation 30 km runs; the term Treatment represents the effect of PCSO-524® (Great HealthWorks) supplemented relative to the control; Time represents the time of the measurement after the 30 km run; the term Treatment · Time represents the interaction of the treatment effect with the time of measurement after the 30 km run, that is whether the treatment varied according to the measurement time; Weight is the body weight of the runner; and the terms Random Pair and Random Subject account for possible effects due to the sample design.

The statistical computation was undertaken using the statistical package GENSTAT version 14 (VSN International Ltd; Oxford, UK). A statistically significant difference between groups was set to $P < 0.05$.

Results

Participants

Some physical characteristics of the participants are shown in Table 2. There were no significant differences between the PCSO-524® (Great HealthWorks) and placebo groups in any of the physiological characteristics associated with the maximal treadmill tests before the treatment.

Training

Training volumes and intensities during the 11 weeks were similar in both groups. Six runners in each group averaged one to two training sessions per week; two in each group average two to three sessions per week; and eight in each group ran an average of three or more sessions per week. One runner in each group averaged less than 10 km per run; ten in the PCSO-524® (Great HealthWorks) group and nine in the control group

Table 2 Characteristics of the participants (medians, 5th and 95th percentiles) and running speed of the repeated standard long run

	PCSO-524 group			Placebo group		
	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
Age (years)	30.2	43.5	53.0	28.5	45.0	50.7
Height (m)	1.62	1.78	1.90	1.66	1.78	1.91
Weight (kg)	59.2	72.5	95.4	56.7	74.0	91.1
BMI ($kg \cdot m^{-2}$)	20.3	23.5	26.8	19.8	23.1	29.3
VO_{2max} ($mL \cdot kg^{-1} \cdot min^{-1}$)	29.6	43.6	52.1	34.7	43.4	55.9
Running V1 ($m \cdot seconds^{-1}$)	2.42	3.06	4.14	2.34	3.07	4.0
Running V2 ($m \cdot seconds^{-1}$)	2.5	3.17	3.81	2.52	3.03	3.85

Note: V1 and V2 are the velocities measured during the first and second 30 km runs, respectively.
Abbreviations: BMI, body mass index; VO_{2max}, maximum oxygen uptake.

averaged 10–15 km per session; five in the PCSO-524® group and six in the control performed more than 15 km on average per session. All runners trained on a flat terrain.

DOMS

A summary of the runners' DOMS is shown in Table 3. We analyzed the treatment effect in two ways. Firstly, on investigation of the changes in DOMS following the pre and posttreatment 30 km runs, there was a significant reduction in DOMS in the PCSO-524® (Great HealthWorks) group ($P < 0.05$) compared to the control group, after accounting for potentially confounding covariates as described above. As illustrated in Figure 1, the PCSO-524® (Great HealthWorks) treatment effect was a reduction of 1.1 units (standard error 0.41) on the 10-point scale.

Secondly, on comparing the responses of runners in the postsupplementation 30 km training run on its own, again with appropriate adjustments, DOMS was lower in the PCSO-524® (Great HealthWorks) group than in the control ($P < 0.05$) during the 48 hour period post run. This effect is shown in Figure 2.

Training was categorized according to training frequency into those who trained three or fewer sessions per week, and those who trained four or more sessions per week. There was evidence of a greater PCSO-524® (Great HealthWorks) treatment effect on DOMS in runners who trained less frequently ($P < 0.05$). In runners who trained no more than three sessions a week, the mean of DOMS in the postsupplementation run was 1.7 in the PCSO-524® (Great HealthWorks) group and 4.0 in the control. For runners who trained four or five sessions a week, the mean of DOMS was 1.6 in both the treatment and control group.

CK concentration

The CK concentrations measured following the pre and posttreatment 30 km runs are shown in Table 4. In the study group as a whole, there was no conclusive evidence of any PCSO-524® (Great HealthWorks) effect on CK levels ($P > 0.1$), although lower mean values (backtransformed from the logarithms used in the statistical analyses) were apparent in the treatment group following the posttreatment 30 km run (367 versus 487 IU/L). Furthermore, similar to the situation for DOMS, the trend toward a treatment effect on the maximal CK was more pronounced in the lesser trained runners. In runners who trained three times a week or less, the median maximum CK level following the second 30 km run was 475 IU/L for PCSO-524® (Great HealthWorks) group, 31% lower than the control group where the mean was 680 IU/L. In the runners who trained four or five sessions a week, the median value of maximal CK after the second 30 km run was 284 IU/L for the PCSO-524® (Great HealthWorks) group, this being 19% lower than in the control group where the median value was 349 IU/L. Taking all values of both runs into account, the more highly trained runners had lower maximal concentrations of CK (569 IU/L compared to 315 IU/L, $P < 0.05$). There was a significant relationship between DOMS and LnCK ($P = 0.05$). A plot of the absolute values is represented in Figure 3.

Discussion

The main finding of the present study is a slight but significant reduction in pain sensation in PCSO-524® (Great HealthWorks) treated nonprofessional distance runners following a 30 km training run. More specifically, this effect was more pronounced in lesser trained runners.

Despite the fact that CK has long been associated with DOMS,[12] analysis of the CK levels following the postsupplementation 30 km run did not reveal a PCSO-524® (Great HealthWorks) treatment effect, but closer analysis of our data did provide some evidence of this effect. Firstly, the PCSO-524® (Great HealthWorks) reduction of DOMS was accompanied by a relationship between DOMS and CK,

Table 3 Medians, 5th and 95th percentiles of DOMS, immediately after, 24, and 48 hours following the pre- and posttreatment 30 km runs

Time after run	PCSO-524® group			Control group		
	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
Pretreatment 30 km run						
0 hours	1.0	3.5	8.7	1.0	2.0	6.0
24 hours	0.3	2.5	5.7	0.3	2.0	7.4
48 hours	0.0	1.0	6.7	0.0	1.0	4.0
Posttreatment 30 km run						
0 hours	1.0	2.0	7.0	1.0	2.0	6.0
24 hours	0.0	1.0	4.4	1.0	2.0	5.0
48 hours	0.0	1.0	2.4	1.0	2.0	3.7

Abbreviation: DOMS, delayed-onset muscle soreness.

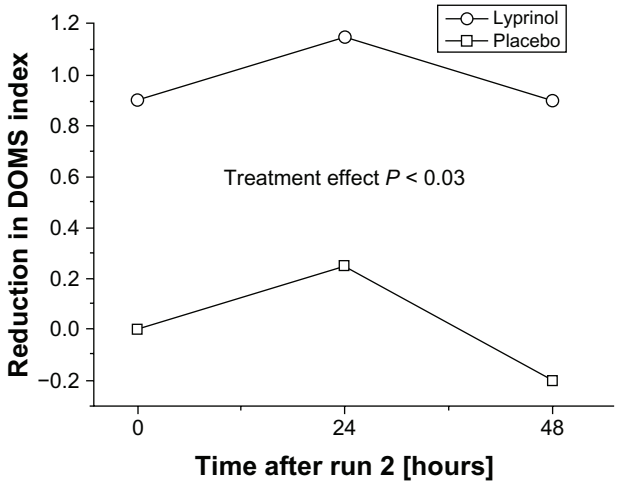

Figure 1 Changes in DOMS after the pretreatment to posttreatment 30 km runs in the PCSO-524® and control groups.
Abbreviation: DOMS, delayed onset muscle soreness.

suggesting the plausibility of an elicited reduction in postrun CK. Secondly, the median maximal posttreatment CK level was 25% lower in the PCSO-524® (Great HealthWorks) group than in the control; and consistent with the DOMS data, this trend was more pronounced in the lesser trained runners. The post treatment median CK in the lesser trained runners was 30% lower in the PCSO-524® (Great HealthWorks) group than in the control group; whereas the equivalent figure for the better trained runners was 19%. Further investigation is required and a study design with greater statistical power is necessary to gain a clearer picture of whether PCSO-524® (Great HealthWorks) supplementation can attenuate the efflux of CK from muscle cells, an effect generally associated with reduced sarcomeric trauma.[13]

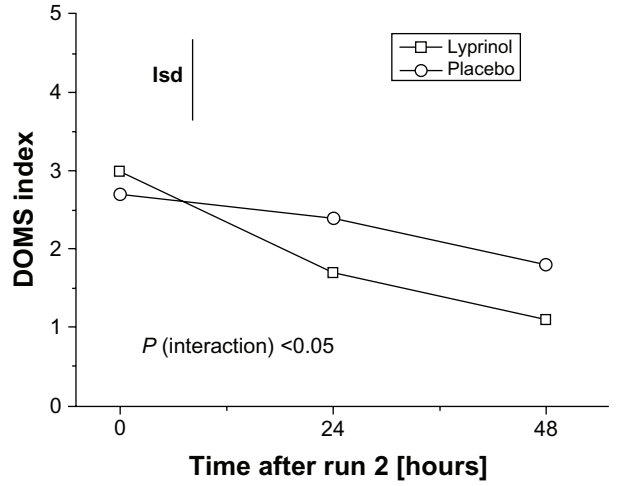

Figure 2 The patterns of DOMS in the PCSO-524® and control groups showing the significance of the interaction after the posttreatment 30 km run.
Abbreviations: DOMS, delayed onset muscle soreness; lsd, least significant difference

Given that effects occurred relative to a control group that took placebo capsules of olive oil, and comparing the differences in composition of the active and placebo capsules (Table 1), the likely candidates for the active components of PCSO-524® (Great HealthWorks) are the ω3 fatty acids eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), as each is known to possess anti-inflammatory properties.[14] These lipids have widespread effects on human physiology, including down-regulating genes controlling inflammatory activity, reducing lipid synthesis and stimulating its oxidation, and influencing cell membrane function.[15] There is also in vitro evidence of their facilitatory effect on skeletal muscle regeneration[16] through inhibition of cytokine activity. The ω3 fatty acids have also been shown to influence psychological function, and currently there is interest in the role of EPA on psychological mood.[15,17,18] Consequently, apart from PCSO-524®'s (Great HealthWorks) peripheral anti-inflammatory properties, this raises the possibility that its effect on DOMS may have occurred, at least in part, through its effect on the central nervous system. Last but not least, an enhancement of antioxidative enzymes has to be taken into account when potential causal effects of PCSO-524® (Great HealthWorks) are considered. Recently, Schmidt et al[20] showed altered expression of genes regulating antioxidative processes after supplementation with fish oil in humans. If their interpretation holds, this effect may be of special meaning for the findings of the present endurance study since mitochondria are the main source of endogenous oxidant production.[21]

Our findings must be viewed alongside two other studies, each of which provide little evidence that EPA or any other component of fish oil or PCSO-524® (Great HealthWorks) itself were effective in reducing DOMS or CK following muscular activity. Firstly, it was reported that fish oil supplementation had no influence on DOMS induced by isokinetic eccentric elbow flexion, nor any effect on the inflammatory markers CK, cytokines interleukin-6, or tumor necrosis factor-alpha.[7] This might suggest that our finding that PCSO-524® (Great HealthWorks) treatment effects DOMS was due to its unique variety of lipids, but another, and indeed the only other published report on the effect of PCSO-524® (Great HealthWorks) on DOMS provides little support for this premise.[19] In that study, the exercise stress comprised intervals of downhill running and 8 weeks of PCSO-524® (Great HealthWorks) supplementation, after which the authors reported no statistically significant effects on DOMS, blood CK, myoglobin, or cytokine levels. However, it is of interest to observe the graphically represented variations

Table 4 Medians, 5th and 95th percentiles of blood CK concentrations associated with the pre- and posttreatment 30 km runs

	Pretreatment 30 km run			Posttreatment 30 km run		
	5th percentile	Median	95th percentile	5th percentile	Median	95th percentile
PCSO-524® group CK (IU/L)						
Before	60.7	109.0	223.6	88.0	129.5	258.8
1-hour	127.0	171.0	335.1	123.8	219.5	481.8
24 hours	144.8	370.5	1037.3	123.3	390.5	903.9
48 hours	101.8	238.0	646.3	117.5	239.5	525.8
Placebo group CK (IU/L)						
Before	66.1	150.0	233.6	82.2	147.0	390.2
1-hour	131.3	237.5	372.0	111.0	237.0	560.
24 hours	190.1	382.0	954.9	111.6	387.0	1471.7
48 hours	139.8	244.5	615.1	87.8	275.5	943.4

Abbreviation: CK, creatine kinase.

between the active and placebo groups. Where minor trends of variation occurred in mean CK, interleukin-6, interleukin-10, and myoglobin levels (in the post 24 hour post exercise period) and DOMS (in the 48–96 hour period) the values were lower in the PCSO-524® (Great HealthWorks) supplemented group. Any interpretations of trends such as these are clearly tenuous, and are raised as a point of interest given the findings of the current study and may again point to a need for greater statistical power in studies concerning highly variable 'snapshots' of blood CK and subjective measurement of DOMS. Any further research on the effect of marine oil supplementation should also consider other factors which may have influenced discordant results between our study and the two cited works. These factors include the dose of PCSO-524® (Great HealthWorks; in the current study was 400 mg/day for 11 weeks compared to 200 mg/day for 8 weeks in the previously mentioned study using this particular marine oil);[19] the age of the subjects (the two prior studies involved younger groups with a mean age of 25 years); the nature and novelty of the exercise stress (the previous studies employed unaccustomed downhill treadmill running intervals[19] or unaccustomed maximum eccentric arm flexor work),[7] as distinct from the sport and training specific running exercise in the current study. It is notable that the non-specific protocols elicited CK levels of about twice the magnitude and much greater range than in the current study, and presumably greater DOMS, although direct comparison with these outcomes is problematical. Further research is required to confirm our findings of the effectiveness of PCSO-524® (Great HealthWorks) in offsetting DOMS in runners, and whether such a finding may be related to the training status, age, familiarity with the exercise stimulus, intensity of the exercise stimulus, or dose.

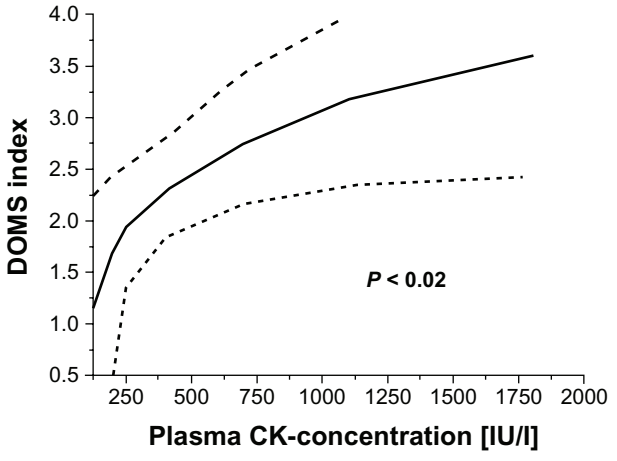

Figure 3 The relationship between DOMS and plasma CK concentration in data from both groups pre- and posttreatment.
Notes: The *P*-value refers to the significance of the relationship between DOMS and the logarithm of CK; the dotted or faint lines represent the 95% confidence intervals.
Abbreviations: CK, creatine kinase; DOMS, delayed onset muscle soreness.

As is typical, our study had its strong points as well as its limitations. The investigation of a long training run rather than unaccustomed muscular activity was of direct practical relevance, particularly to runners and coaches. The involvement of our statistical model that facilitated adjustment for potentially confounding covariates and avoided the undesirable practice of multiple time point comparisons was also a solid aspect of this study. On the other hand, the lack of precision of measurement of the two primary outcome measures, DOMS and CK, was a limitation that would tend to reduce the chances of finding significant effects. The DOMS estimate relied on the consistency of each individual's perception and rating of pain following 30 km runs 11 weeks apart and the three postrun plasma concentrations of a rapidly changing CK may not accurately or reliably reflect released CK volumes. However, any potential inaccuracy and unreliability would reduce the

chances of finding a treatment effect, perhaps increasing confidence in our finding of an effect on DOMS. Our single blind design was also not ideal, although neither of the main outcome measures were reliant on personal judgment by any of our research teams so this fact should not have influenced our results. Although speculative, upcoming studies should also take into account a possible effect of olive oil itself on muscle soreness and, therefore, may consider a different placebo. Finally, our participants were a group of predominantly male club runners of a median age of 45, with a range of 30 years, and our conclusions may not apply to more accomplished and/or younger runners, or indeed to athletes in other disciplines.

In conclusion, our data indicate that PCSO-524® (Great HealthWorks) supplementation attenuated DOMS in a group of club runners following a 30 km training run, an effect which was greater in lesser trained runners. This effect was accompanied by a trend towards lower postrun CK concentrations in the supplemented group compared to the control group, this trend being consistent with our findings that CK levels reflected DOMS. In addition to the generally accepted benefits of increasing the intake of ω3 fatty acid in western diets, our findings suggest that PCSO-524® (Great HealthWorks) supplementation is likely to assist veteran age distance runners recover from the muscular stress induced by long training runs.

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Disclosure

The authors report no conflicts of interest in this report.

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